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THE
JOURNAL OF GEOLOGY

FEBRUARY-MARCH, 1901

ON THE ORIGIN OF THE PHENOCRYSTS IN THE PORPHYRITIC GRANITES OF GEORGIA[1]

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INTRODUCTION.[2]

UNTIL quite recently, the idea has been prevalent among petrographers, that porphyritically developed minerals (phenocrysts) in intrusive igneous rocks were of intratelluric[1] origin. Indeed, as pointed out by Pirsson, no sharp distinction heretofore has apparently been drawn in the literature, between the origin of phenocrysts in intrusive and extrusive igneous rocks; indicating probably, that the porphyritically developed mineral or minerals were of the same origin in the two rock divisions here designated, and were formed at much greater depths than the place in which they are now found. The idea that phenocrysts in intrusive igneous rocks are not always of intratelluric origin, but have, in many cases, been formed *in place*, and are therefore contemporaneous in origin, with a part at least, of the other rock constituents, was advocated by Zirkel[2] in 1893; by Cross[3] in 1895; and more recently by Pirsson[4] and Crosby.[5]

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[1] Published by permission of the State Geologist of Georgia.

[2] The writer wishes to acknowledge his indebtedness to Professor A. C. Gill, of Cornell University, for kindly reading and criticising this paper in manuscript.

Pirsson and Crosby are agreed in dissenting from the old and long-accepted theory, that appreciable or abrupt changes in the ratio of cooling and the viscosity of the magma, are essential elements in the development of the porphyritic structure — phenocrysts and groundmass — in intrusive igneous rocks.

A careful field study of the granitic rocks of Georgia, by the writer, during the seasons of 1898, 1899 and 1900, shows a number of extensive areas of coarse-grained porphyritic granites occurring within the limits of the Georgia Piedmont plateau. The distribution of the porphyritic granite areas is given on the accompanying map. The interior gradation or passage of the porphyritic facies, peripherally, into an even-grained coarse-textured non-porphyritic granite of the same mineral and chemical composition, is readily traceable in most of the granite areas.

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[1] The term "intratelluric" is here used in the same sense as that given it by Pirsson in the Amer. Jour. Science, 1899, Vol. VII, p. 272, "meaning an earlier period and greater depth of the magma than that in which it came to rest."

[2] Lehrbuch der Petrographie, 1893, Vol. I, p. 737 et seq.

[3] Laccolitic Mountain Groups, U. S. Geol. Surv., Fourteenth Annual Report, 1895, p. 231.

[4] On the Phenocrysts of Intrusive Igneous Rocks, Amer. Jour. Science, 1899, Vol. VII, pp. 271–280.

[5] On the Origin of Phenocrysts and the Development of the Porphyritic Texture in Igneous Rocks, Amer. Geol. 1900, Vol. XXV, pp. 299–310.

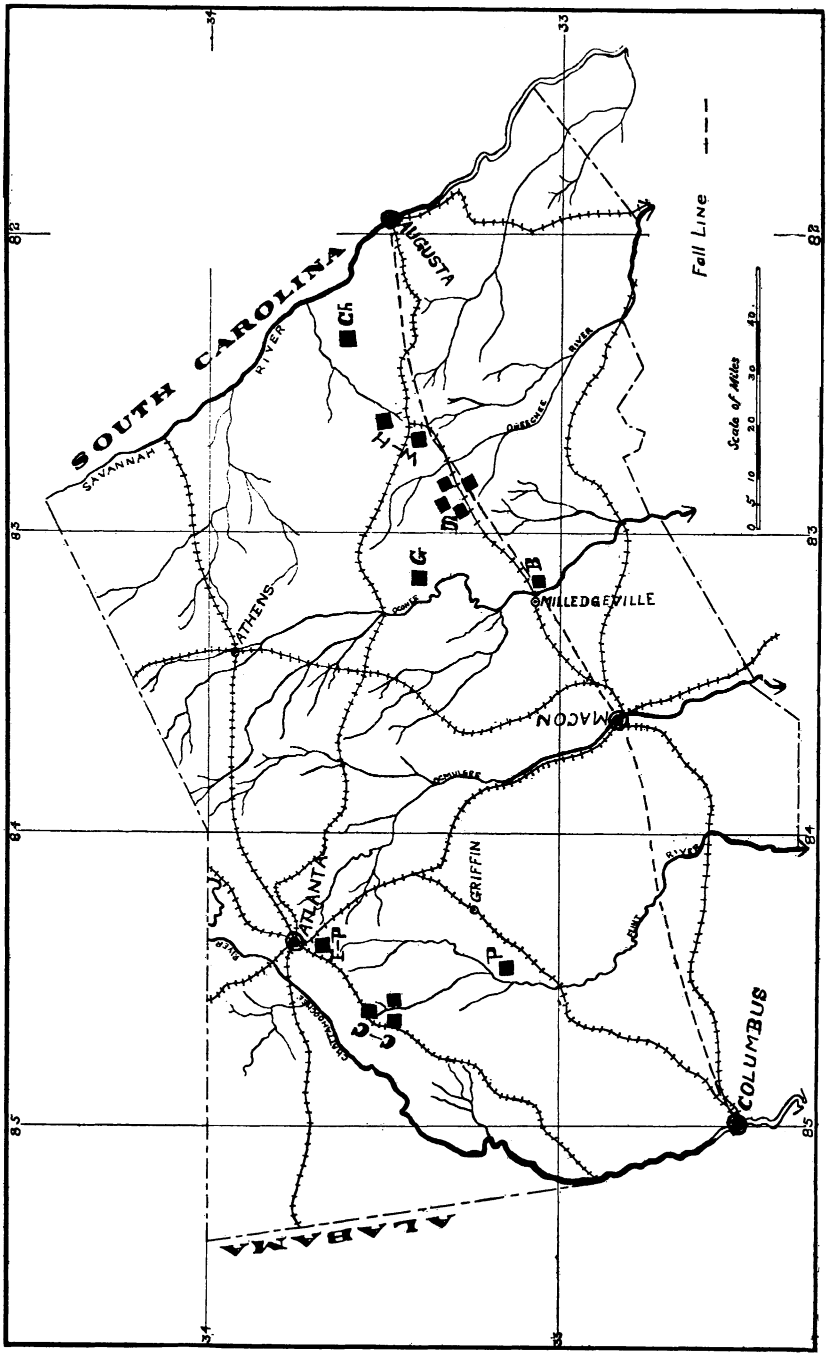

FIG. 1.—Map of Piedmont, Georgia, showing distribution of porphyritic granite described in the text.

The size, development and character of the phenocrysts in the porphyritic portions of the areas; and the gradation from one rock facies into another of the same composition shown in the same rock-mass, unquestionably point to contemporaneous growth with the groundmass constituents, and have, therefore, been formed *in place* and not at greater depths—intratelluric. In the present paper, it is proposed, therefore, to give a brief description and summary of the individual porphyritic granite areas; and to state the reasons for the belief in the contemporaneous origin of the phenocrysts with the groundmass constituents, based on a careful field and laboratory study of these rocks.

DESCRIPTION OF INDIVIDUAL AREAS

The Fayette-Campbell-Coweta counties porphyritic granite area.[1]— This area, marked C–C on the accompanying map, is thirty miles southwest from Atlanta and occupies contiguous portions of Campbell, Coweta and Fayette counties. The rock-outcrops are usually small and in the nature of bowlder and flat-surface masses. The exposures are most numerous in the vicinity of Palmetto and Coweta Stations on the Atlanta and West Point railroad, and near Line Creek in Fayette county. Specimens of the porphyritic rock collected from the outcrop near Line Creek in Fayette county are somewhat lighter in color than similar ones from the Palmetto-Coweta portions of the massif. The ratio of quartz to biotite in the Line Creek outcrop is visibly greater than in the Campbell-Coweta exposures, as indicated in analyses II and XI, p. 119. The rock, however, is generally quite uniform over the entire area. Several good contacts of the partially decayed porphyritic granite and mica-schist are exposed along the wagon roads and in the cuts of the railroad, traversing the area. The field relationships of the two rocks indicate, that the porphyritic granite is the younger rock; intruded into the overlying schist, and exposed subsequently by erosion.

The rock is a very coarse-grained porphyritic-biotite granite of a medium, light to dark gray in color, according to the amount of biotite present. The extreme coarseness of texture renders the porphyritic structure less typically marked in this than in finer grained porphyritic rocks. The porphyritically developed mineral (feldspar) grades imperceptibly from very large, irregular, sometimes stout, tabular phenocrysts, into the smaller feldspars, making it difficult usually to distinguish between groundmass and phenocryst feldspars, except in extreme cases.

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[1] Eighteenth Annual Report, U. S. Geol. Surv., 1898, pp. 551–572.

The feldspar phenocrysts vary from extremely irregular cleavable grains, anhedra, 30 by 30^{mm} to roughly idiomorphic crystals; tabular, parallel to the clinopinacoid (010), and twinned according to the Carlsbad law. Abundant inclusions of large irregular plates of biotite are readily visible in all the phenocrysts to the unaided eye. The phenocrysts are prevailingly allotriomorphic in outline and differ in this respect from those of the other areas described below. The feldspars are white in color, usually partially cloudy or opaque rather than limpid in appearance.

The biotite occurs as stout cleavable plates averaging 10–15^{mm} in size, occupying somewhat well-defined areas; is very dark in color, and highly lustrous. The quartz is present in large irregular colorless and smoky anheda, 4–5^{mm} in size, clearly outlined against the feldspar and biotite, from which it is readily distinguished.

Microscopic study of thin sections of the porphyritic granite confirms the macroscopic description, in affording no marked differentiation between groundmass feldspar and a part of the similar porphyritic constituent, or phenocryst.

The feldspar constituent is composed of the potash varieties, orthoclase and microcline, and a fair proportion of an acid plagioclase, which from its optical properties is near oligoclase. The presence of considerable lime in the analysis tends to corroborate this inference. The orthoclase usually shows good cleavage, and is separately intergrown with stringers of albite and quartz, in the form of microperthitic and micropegmatitic structures. The potash feldspars and quartz of the groundmass are entirely allotriomorphic in crystal outline. The plagioclase feldspar occurs in roughly idiomorphic lath-shaped crystals characterized by the polysynthetic twinning, and, as a rule, afford very small extinction angles in basal sections.

The porphyritically developed minerals (phenocrysts) are composed of both orthoclase with numerous microperthitic structures, and microcline, usually inclosing inequidimensional anhedra of quartz, feldspar and biotite without definite optical orientation. The more basic inclusions, accessory apatite and zircon are also included in the phenocrysts.

A thin section of one of the feldspar phenocrysts from the Coweta portion of the area, shows the characteristic microcline structure, and contains abundant inclusions of irregularly bounded crystals of feldspar, quartz and biotite; several rounded disks or ovals of micropegmatitic intergrowths of quartz and feldspar, and prismatic needle-like inclusions of apatite and zircon (see Fig. 2.) A chemical analysis of fragments of carefully selected phenocrysts from hand specimens of the Coweta outcrops of the rock is given in XI a, page 119.

The biotite occurs as aggregated intergrown shreds with deep brown color, good basal cleavage and strong absorption, partially altered to chlorite and some epidote. The biotite is intergrown with occasional foils of muscovite, and sometimes shows good crystallographic boundaries. In addition to these, prismatic inclusions of apatite and zircon and a few grains of magnetite are present. The effects of dynamo-metamorphism are generally indicated to some degree in the rock by numerous fracture-lines and undulatory extinction common to the larger quartz and feldspar individuals.

Cubes[1] from the Rockingham, Richmond county, and Mt. Monroe, Iredell county, granite areas in North Carolina, very closely resemble in color, grain and texture the Campbell-Coweta-Fayette counties porphyritic granite, in Georgia. The phenocrysts in the Carolina rock are usually allotriomorphic, occasionally idiomorphic, in crystal outline; and, as a rule, are large in size, and contain numerous plates of included biotite. A similar though darker colored rock, owing to a greater amount of biotite present, occurs in Aiken county, South Carolina. The porphyritic feldspars in the Aiken rock present the same characteristics as the phenocrysts of the Georgia and North Carolina porphyritic granites.

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[1] Through the kindness of Dr. George P. Merrill, Head Curator, Department of Geology, U. S. National Museum, the writer was accorded access to the Tenth Census Collections of Building Stones in the Museum.

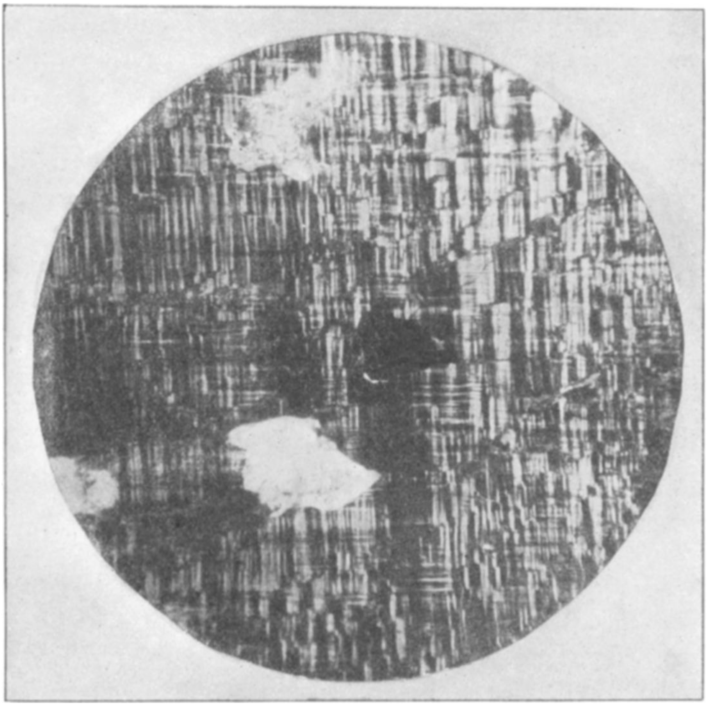

FIG. 2.—Photomicrograph of a phenocryst of microcline from the Coweta county porphyritic granite area, showing inclusions of quartz, plagioclase and biotite. The inclusions of plagioclase and biotite are considerably altered. Crossed nicols. Magnified 74 diameters.

The Hancock county porphyritic granite area.—A coarse-grained porphyritic granite outcrops one quarter of a mile east of Sparta depot, with the exposures more or less continuous from this point, for eleven miles, in a northeastwardly direction, along the Georgia railroad. The area lies near the merging of the crystalline rocks beneath the Coastal Plain sands and clays — the Fall-line (area marked S on the map). It is elliptical in shape with its longer diameter eleven miles in length, trending northeast-southwest. The granitic rock outcrops as bowlder and flat-surface masses, frequently containing four to five acres of exposed rock in one body.

The rock texture is prevailingly porphyritic, grading, in many cases, into a non-porphyritic, even-grained granite of the same mineral and chemical composition. In several quarries the rock shows in places a somewhat pronounced gneissoid structure. Some half dozen quarries have been extensively worked in various places over the area, within a few miles northeast of Sparta.

The rock is prevailingly a coarse-grained, medium gray, porphyritic biotite-granite. The phenocrysts are composed of the potash feldspars having a pronounced pinkish cast which disappears in thin section. They are flat tabular in crystal form, averaging 20^{mm} in length parallel to the clinopinacoid (010). Carlsbad twins of the contact type are common. The phenocrysts are further characterized by numerous inclusions of all the groundmass minerals.

The porphyritic feldspars are embedded in a coarse-grained groundmass of quartz, potash and soda-lime feldspars and biotite, with some accessory muscovite, chlorite, apatite, zircon, epidote and scattered grains of magnetite. Microperthitic structures are common to the potash feldspars. Micropegmatitic structures are less frequently observed, than in some of the other areas. The rock from the Sparta area differs from that of the Campbell-Coweta-Fayette counties area in containing less biotite, and hence, lighter in color; in the phenocrysts being idiomorphic instead of allotriomorphic in crystal outline, and usually of a pinkish cast rather than white in color. Microcline is, alike, variable for the two areas in thin sections of the rock examined from various places. The relative proportion of the component minerals is, including all species present, feldspar > quartz > biotite.

Like the former area, the Sparta porphyritic granite is surrounded on all sides by mica-schist; but the great depth of residual decay of the granite and schist, renders exposures of the contact between the two impossible. The field relationships however, indicate, as in the above area, that the granite is the younger rock, intrusive into the then overlying schist.

The Baldwin county porphyritic granite area.—Large bowlder outcrops of a coarse-grained porphyritic granite occur three miles southeast from Milledgeville, the county seat of Baldwin. Like the Sparta area, the Baldwin county porphyritic granite mass is located near the line of contact (Fall-line) between the Piedmont crystallines and the Coastal Plain sediments (area marked B on the map).

Hand specimens of the granite from Baldwin county are indistinguishable from similar specimens of the Columbia county porphyritic mass, described below. The rock is a very coarse-grained porphyritic granite, composed of an aggregate of interlocking quartz and feldspars—orthoclase with microperthitic structures, microcline and plagioclase—with intergrown shreds of biotite. The rock varies in color from medium to dark gray. Both microcline and orthoclase occur in the groundmass and as porphyritically developed minerals. The phenocrysts measure in extreme cases 30–40^{mm} long and 5–10^{mm} broad. They are prevailingly idiomorphic in form; flat, tabular parallel to the clinopinacoid (010), and commonly twinned according to the Carlsbad law. Abundant inclusions of black biotite foliae are plainly visible to the unaided eye in the feldspar phenocrysts; while the microscope shows additional numerous irregularly bounded quartz and feldspar grains without definite orientation.

The groundmass is composed of an abundance of white opaque feldspars, slightly dark-colored smoky quartz, and biotite plates measuring 2–5^{mm} in diameter. The microscopic accessories are primary inclusions of apatite and zircon and scattered grains of magnetite, with some secondary muscovite, chlorite and epidote derived from the alteration of the feldspars and biotite. Bent and curved filaments of rutile are quite abundant as inclusions in the larger quartz crystals. The effects of slight pressure metamorphism are evident in the lines of fracture and undulous extinction common to the larger quartz and feldspar individuals.

The Warren county porphyritic granite area.—Two somewhat extensive outcrops of foliated porphyritic granite occur in the middle eastern portion of Warren county, approximately ten miles from each other, in an almost east and west direction. These are known as the Holder's-Mill and Brinkley-Place granite masses, respectively, and marked W–H on the map.

The rock has a pronounced secondary foliated structure. The quartz and feldspar crystals are drawn out and inclosed between the biotite layers, forming at times distinct "augen" of the two light-colored minerals. The rock contains abundant black biotite plates arranged along somewhat parallel lines. The quartz and feldspar grains are greatly squeezed and mashed, and are more or less drawn out in directions parallel with the biotite layers, as a result of metamorphic action. The porphyritic granite of this area owes its foliated structure, therefore, to pressure metamorphism,[1] so common to many igneous rock masses in those regions subjected to mountain-building forces. Hence it is derived or secondary and not primary or fluidal.

The feldspar phenocrysts are composed principally of microperthitic orthoclase with some microcline 15–20^{mm} long; are white opaque to pink in color; contain numerous inclusions of biotite plates, and exhibit the usual habit of Carlsbad twins. They are prevailingly irregular in crystal outline and badly fractured from subsequent intense metamorphism. The porphyritic feldspars are embedded in a coarse-grained groundmass of quartz, feldspar and biotite. The groundmass feldspathic constituent consists of the potash feldspars with microperthitic structures, and some laths of plagioclase near oligoclase. The large feldspar individuals (phenocrysts) contain inclusions of irregularly bounded crystals of quartz, biotite and other feldspar species. These inclusions are usually round, oval shape in outline. The quartz and feldspar anhedra are variously interlocked as fine and coarse-grained mosaics. The finer-grained mosaics of the two minerals represent the peripheral shattered portions of the larger feldspar and quartz crystals. Micropegmatitic structures, intergrowths of quartz and feldspar, are very common. Biotite occurs as grouped shreds and plates, deep brown to occasional green in color, with strong absorption and good basal cleavage. It is partially altered to a dark opaque chlorite and occasional crystals of slightly pleochroic and strongly double refracting epidote. A few scattered grains of magnetite are observed.

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[1] Gregory has established, according to origin, three classes of gneisses, namely, metapyrigen-gneisses, clastic-gneisses, and fluxion-gneisses. See Quart. Jour. Geol. Soc. (London), 1894, p, 266; DALY, R. A. JOUR. GEOL. (Chicago), Vol. V, p. 780.

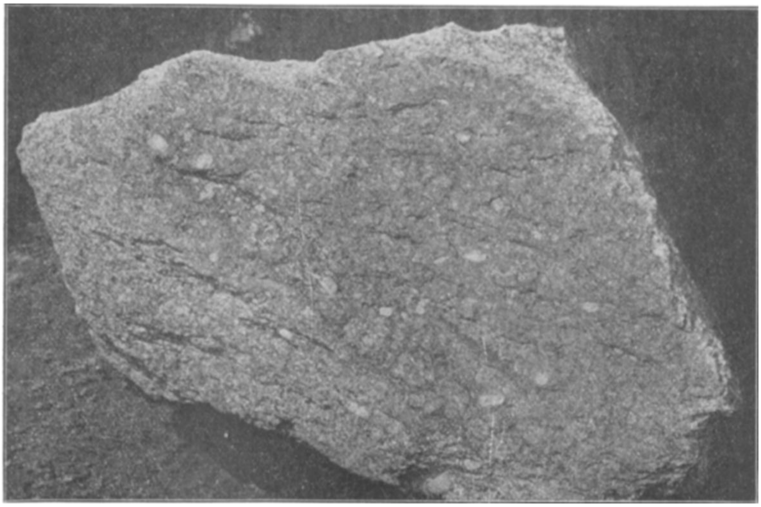

FIG. 3.—The Virginia type of foliated porphyritic granite near Chatham, Va.

An outcrop, from which some rock has been quarried, of a similar dark-colored, foliated biotite porphyritic granite is found near Chatham depot, Pittsylvania county, Virginia. The feldspar phenocrysts are very large in size, 40–50^{mm} long, roughly tabular in outline and twinned according to the Carlsbad law, and shows an abundance of large included biotite shreds (see Fig. 3).

Still a third exposure of granitoid rock showing a pronounced porphyritic texture in places, occurs six to eight miles south of the Holder's Mill-Brinkley Place area. It differs quite strongly from the Holder's Mill-Brinkley Place granite in the porphyritic texture being less strongly marked and finer grained; in containing less biotite, and is massive instead of foliated in structure. It further differs from the former area in containing a larger proportion of plagioclase, and a smaller percentage of microcline feldspars. Only one included grain of microcline was found in a number of thin sections studied of this rock. The feldspar phenocrysts are deep pink in color, 5–10^{mm} long, displaying the usual characteristic twinning and cleavage; and carry numerous inclusions of all the groundmass minerals.

The Greene county porphyritic granite area.—The Greene county porphyritic granite area, marked G on the accompanying map, includes at least 100 acres in the main granite outcrop, located ten miles south of Greensboro, in the southern part of the county. The main central exposure is in the form of a low flat doming-mass with a roughened and irregular surface, and partially covered, in places, with a thick growth of cedars (see Fig. 4).

An even granular medium coarse-grained granite outcrops in bowlder form three miles south of Greensboro, and is continuous along the public highway from this point to the main porphyritic granite mass (see Fig. 5). The true granitic facies of the rock mass grades interiorly into the typical porphyritic granite facies. The even-grained granitic portion of the mass representing the outer or peripheral zone, indicates some variation in mineral composition, from place to place, along a north and south section. The zone nearest the porphyritic area, two and one half miles north therefrom, and showing absence of all trace of porphyritic texture, is a medium-grained biotite granite agreeing, microscopically, in mineral composition, and in chemical composition as well, with the porphyritic granite.

Five miles north of the central porphyritic mass are outcrops of a coarse but close compact-grained granite, containing only a very small amount of biotite. The feldspars show pronounced pink and greenish tints.

About four miles south of Greensboro, on the north side of Beaver-Dam Creek, is an outcrop of practically the same granite. The quartz is decidedly dark in color and of the smoky variety; the feldspars are flesh colored, and the rock contains but little mica.

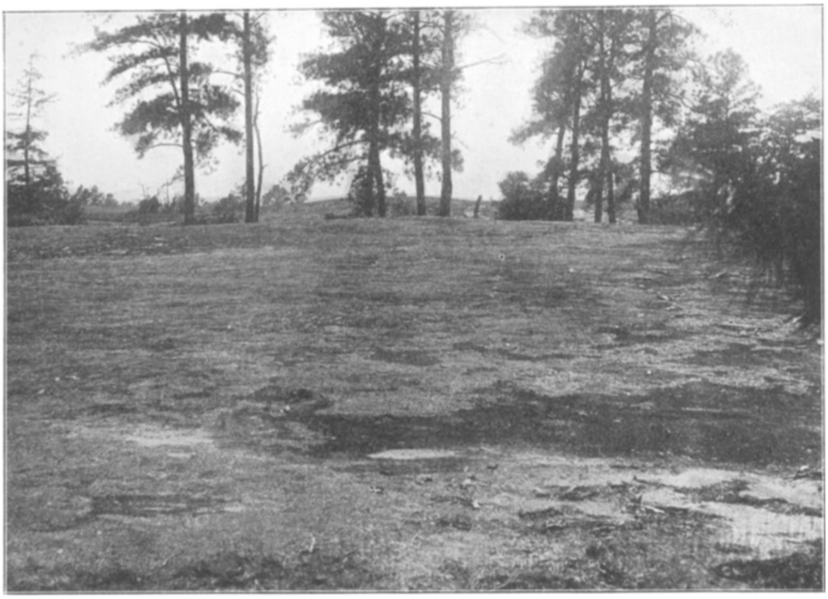

FIG. 4.—The Greene county porphyritic granite area.

The porphyritic facies of the rock consists of a coarse-grained, light-gray groundmass of quartz, feldspar and biotite, in which are embedded large, flat tabular feldspar phenocrysts. The porphyritic feldspars average 30–50^{mm} long and 10–15^{mm} broad; and indicate the usual elongation parallel to the clinopinacoid (010), and Carlsbad twinning. The phenocrysts are deep pink to perfectly white in color, and are usually cloudy and opaque in appearance.

A thin section of one of the phenocrysts under the microscope showed the feldspar variety, microperthitic orthoclase. The microscope further showed abundant inclusions of fairly large crystals of feldspar, twinned, in several cases, after the albite and Carlsbad laws; and allotriomorphic crystals of quartz and biotite with partial orientation with the (010) cleavage. (Fig. 6.) As a rule, however, the inclusions show no definite orientation. The biotite inclusions are always sufficiently large to be visible to the unaided eye.

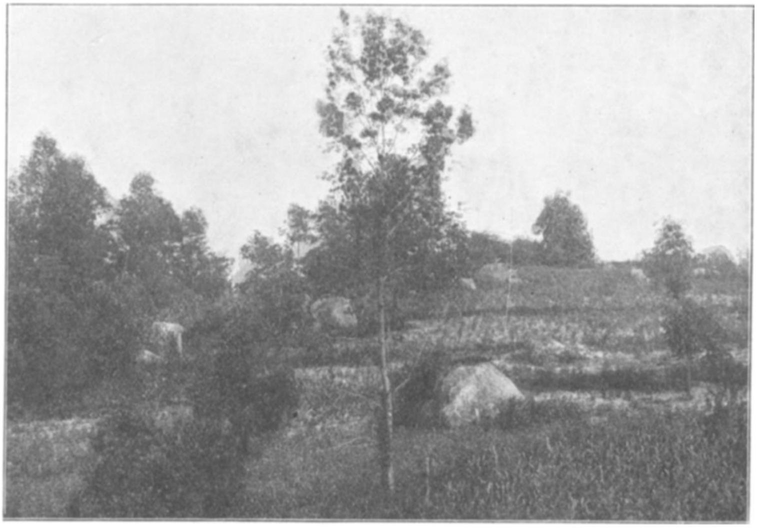

FIG. 5.—Bowlder outcrops of granite near central mass of the Greene county porphyritic granite area.

The ratio of phenocryst to groundmass is quite variable; the probable extremes being represented by the following estimated ratios; 1 : 1 and 2 : 1, with all gradations between. The individual mineral grains vary from a few millimeters to 5 and 6^{mm} in size. The arrangement of phenocrysts in occasional small portions of the mass is suggestive of fluxion structure.

The potash feldspars, orthoclase and microcline, are the porphyritically developed minerals. The orthoclase contains numerous microperthitic structures. Plagioclase is somewhat abundant. Small-rounded disks or ovals of micropegmatitic structures are common. The larger feldspar and quartz crystals indicate slight peripheral shattering in some of the thin sections.

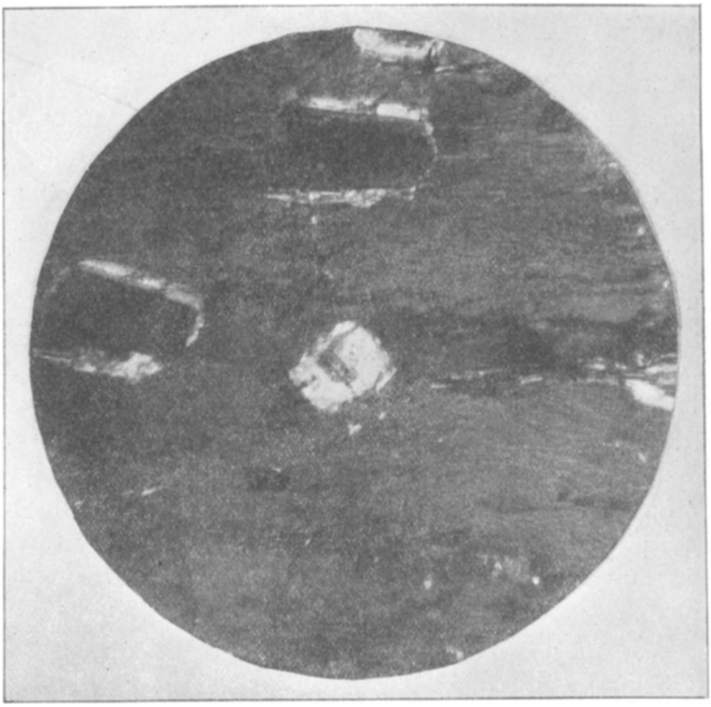

FIG. 6.—Photomicrograph of a phenocryst of microperthitic orthoclase from the Greene county porphyritic granite area, showing inclusions of quartz, plagioclase, biotite, and very small prisms of apatite. Crossed nicols. Magnified 74 diameters.

The biotite is considerably altered to chlorite and some epidote, and at times carries inclusions. Scattered grains of magnetite and prismatic inclusions of apatite and zircon are present in microscopic proportions.

The Columbia county porphyritic granite area—Heggie Rock.— This area, marked Ch on the accompanying map, is located near the Fall-line—contact between the Piedmont crystallines and the Coastal Plain sediments—and a short distance west of the Carolina line.

One and three quarter miles east of Appling, the county seat of Columbia, is an outcrop of a coarse-grained porphyritic granite. The feldspars are slightly pink in color with a somewhat greenish cast in places. The phenocrysts measure 20–35^{mm} in length and 5–15^{mm} broad; and commonly show the contact type of Carlsbad twins.

Microscopically, the rock is composed of a coarse-grained groundmass of potash and plagioclase feldspars, orthoclase predominating, and quartz with biotite and occasional large plates of muscovite. The phenocrysts are large tabular microperthitic orthoclases. The anhedra of quartz vary in size and are badly fractured. Laths of polysynthetically twinned plagioclase are more abundant in this than in many of the other areas. Pegmatitic intergrowths of quartz and feldspar are sparingly present. The large feldspar phenocrysts contain abundant inclusions of the groundmass minerals, especially biotite and plagioclase.

The main porphyritic granite mass is one and one quarter miles further east. The rock outcrops as a large doming-mass. The porphyritic facies of the granite-mass is readily traceable peripherally into an even granular medium coarse-textured granite. The even granular facies of the rock mass is best exposed along the public highway three miles slightly east of south from Appling. Hand specimens of the rock from the two exposures cannot be distinguished from each other. The porphyritic feldspars in the principal exposure are larger but show the same idiomorphic and other microscopic tendencies, developed in the smaller one.

A thin section of one of the phenocrysts from the main outcrop showed the characteristic microcline structure, with numerous inclusions of irregularly bounded crystals of all the groundmass minerals. A chemical analysis of carefully selected fragments of phenocrysts from this rock, yielded the writer the results given in IVa, page 119.

The phenocrysts are embedded in a close and firm, but coarse-grained groundmass of flesh-colored feldspars tinged a slight greenish cast, somewhat dark smoky quartz, and biotite. The porphyritic feldspar crystals make up nearly one half of the total rock. The feldspars are white and opaque rather than pink in color over the greater part of the exposure. This rock very closely resembles that from Greene county in the hand specimens. Here, as in the areas described above, the feldspathic constituent consists of the potash and soda-lime feldspars, with the potash varieties predominating. The porphyritic feldspars are chiefly orthoclase with some microcline, carrying inclusions of all the groundmass minerals. The included biotite shreds are visible macroscopically. Some of the largest plagioclase inclusions in the orthoclase phenocrysts carry, in turn, microscopic inclusions of quartz and other groundmass minerals. Twinning according to the Carlsbad and albite laws among the included feldspar species is commonly observed.

Biotite shows its usual characteristic optical properties, and is partially altered to chlorite and epidote. Muscovite is sparingly present as foils intergrown with the biotite. Sporadic accessory magnetite and apatite occur.

The Pike county granite area.—The Pike county granite area, marked P on the accompanying map, includes fifty or more acres of exposed flat-surface rock in the northwest part of the county. The porphyritic facies of the rock gradually passes into the even-textured medium-grained granite. Only a small proportion of this area, however, shows the porphyritic texture.

The rock is a medium-grained biotite granite, varying from even granular to porphyritic in texture, showing a partial gneissoid structure in places.

Microscopically, the porphyritic portions of the rock are composed of orthoclase phenocrysts in a coarse-grained groundmass of quartz, microperthitic orthoclase, microcline and some soda-lime feldspar, biotite, and occasional intergrown shreds of muscovite. Biotite is the chief accessory mineral. It is deep brown to yellow in color, with strong absorption, and is intergrown with some muscovite. It is more or less altered to dark green opaque chlorite, and to a less degree, to a faint brown pleochroic epidote. Inclusions of prismatic apatite and zircon, and rounded disks or ovals of micropegmatitic structures are very common.

The phenocrysts consist of the potash feldspars, orthoclase and microcline, 10–30^{mm} long and 5–10^{mm} broad; tabular parallel to the clinopinacoid (010). Carlsbad twinning is common. Inclusions of biotite foliae equally as large as those occurring in the groundmass are very abundant in the phenocrysts. In addition to the biotite, they contain microscopic inclusions of irregularly bounded crystals of the interstitial quartz and feldspar.

The Fulton county porphyritic granite area.—The Fulton county porphyritic granite area, marked E–P on the accompanying map, is exposed in bowlder form over a large territory six miles south of Atlanta, in the extreme southern part of the county. The gradation from the interior porphyritic facies, peripherally, into an even-grained granite of the same color and texture, and having the same mineral and chemical composition, is more gradual and more strikingly shown in this than in any one of the previously described areas. Near the center of the granite mass the phenocrysts compose more than 50 per cent. of the entire rock, while near the transition zone—change of the porphyritic to the non-porphyritic texture—the phenocrysts are very sparingly present, not more than a half dozen are shown in a yard square of the rock surface. Near the center, the phenocrysts are prevailingly idiomorphic in crystal outline, while the allotriomorphic type of phenocryst characterizes the transition zone of the rock mass.

The rock consists of a medium coarse-grained groundmass of quartz, the potash feldspars, orthoclase and microcline, numerous laths of polysynthetically twinned plagioclase, biotite, and some muscovite, in which are embedded large potash feldspar phenocrysts. Accessory apatite, magnetite, and zircon; and the alteration products, muscovite, sericite, chlorite, and kaolin are noted. The microscope shows the feldspars and biotite to be considerably altered in some cases.

Microcline and orthoclase occur porphyritically developed, and measure 15 to 50^{mm} in length. The phenocrysts possessing idiomorphism usually display the Carlsbad habit of twinning, and are elongated in the clinopinacoidal direction.

A thin section of one of the phenocrysts showed the characteristic microcline structure and numerous inclusions of quartz, biotite, and the groundmass feldspars, which measure as much as one millimeter in size. Prismatic crystals of apatite and zircon, as inclusions in both the phenocryst and the included groundmass feldspars of the porphyritic crystal, are numerous. The zircon crystals are sometimes grouped in threes, much after the manner of penetration twins.

RÉSUMÉ

Since the individual areas have been described in some detail, it is important that a general summary of the essential features common to the several porphyritic granite masses be given. These can best be summarized under the two headings, *macro-* and *microscopic* features.

Macroscopic features.—The same textural and structural characteristics and relationships are generally developed in all the individual porphyritic granite areas. With the exception of the Warren (W–H) county area, the rocks are prevailingly massive, coarse-grained, porphyritic granites, varying, according to the proportion of biotite present, from dark to medium gray in color. The Warren county granite differs structurally from that of the other areas in possessing a marked foliated structure, resulting from dynamic metamorphism, which is accordingly secondary. Further evidence already mentioned of dynamic action in this rock mass is apparent microscopically. Evidence of a partial gneissoid structure is indicated in portions of several of the other areas, but, as a rule, the rock is generally massive.

Field study shows the development of the porphyritic texture in the interior of the rock masses, with the even-granular granitic facies having the same mineral and chemical composition forming the marginal or body portion. Gradation from one rock facies into the other was not entirely clearly defined in all of the granite masses, owing to lack of exposures of the fresh rock, but could be easily traced in many. The feldspar phenocrysts are irregularly distributed through the coarse-grained groundmass without definite arrangement or orientation. The fluxion primary structure was not entirely evident in any one of the areas studied.

Microscopic features.— Microscopically, the rocks are as nearly identical as is possible for separate areas to be. They contain, in every case, the same minerals, both essential and accessory, in nearly the same proportions. They are composed of admixtures of the feldspars and quartz, in which lie stout plates of biotite. The relative amounts of the component minerals may be expressed as follows: feldspar, including all species present, >quartz>biotite. Biotite is the chief accessory and varies somewhat in quantity for the individual areas. In a number of the sections the biotite is intergrown with occasional foils of muscovite. The potash feldspar varieties of the groundmass predominate and are prevailingly allotriomorphic in crystal outline. Both orthoclase and microcline occur with the former in excess. The plagioclase crystals are roughly lath-shaped in outline, and, as a rule, afford small extinction angles in basal sections, which indicates an acid feldspar near oligoclase. The presence of considerable lime and soda in the analyses corroborates the inference. The orthoclase feldspar shows microperthitic intergrowths with a second feldspar, probably albite. In all the sections some of the feldspar crystals show a micropegmatitic intergrowth with quartz, which takes the form of rounded disks or ovals, and are not of the arborescent or radiate growth type.[1] There can be little doubt that this structure is primary in the porphyritic granites as a whole, affording evidence of simultaneous crystallization of the quartz and feldspar. The quartz occurs in irregular interstitial grains of varying size, and is very common in drop-like inclusions in the feldspars. Prismatic inclusions of apatite are the most common of the primary accessories. Some zircon and a very little magnetite occur. More or less chlorite, some epidote and muscovite are present as constant secondary products from the alteration of the biotite and feldspars. In many of the sections, the effects of pressure metamorphism are frequent in the nature of crushing, lines of fracture, and undulatory extinction common to some of the larger quartz and feldspar crystals.

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[1] See ROMBERG in N. J. B. B.—B., 1892, Vol. VIII. MATHEWS, E. B.: JOUR. GEOL., 1900, Vol. VIII, p. 231.

The potash feldspars are the only porphyritically developed minerals. The phenocrysts vary from allotriomorphic to flat tabular idiomorphic crystals in outline, in which the (001) and (010) cleavages are usually well developed, and are elongated in the clinopinacoidal direction. The usual habit of the simple Carlsbad twins prevails. The idiomorphic type of phenocryst greatly predominates over the allotriomorphic form. As a rule, the phenocrysts are very conspicuous, and are readily differentiated from the groundmass feldspars; although in the Coweta-Campbell-Fayette counties area (C–C) the phenocrysts and a portion of the groundmass feldspars seemingly grade into each other. The phenocrysts invariably contain inclusions of a majority of the groundmass constituents, some of which are visible to the unaided eye. The inclusions are distributed, as a rule, through the rock without regard to any definite arrangement or orientation.

CHEMICAL COMPOSITION

The marked uniformity in the mineral composition of the various porphyritic granites from the individual areas, suggests similar uniformity in chemical composition. The usual amount of free quartz common to this class of rocks; the abundance of potash feldspar, with somewhat increased amounts of plagioclase and proportionally small amounts of accessory minerals, indicate a normal percentage of silica and lime, an increased percentage of alkalies, and comparatively small amounts of iron and magnesium oxides. These inferences are well shown in the following analyses, made by the writer, in the laboratory of the State Survey. Attention is called in the table of analyses to the prevailingly high percentage of soda in all of the rocks described above. In nearly half of the analyses, the soda is slightly in excess of the potash, and in the remaining ones it nearly equals or is but slightly less than the potash. This high range in soda is traceable, first, to the prevalence of microperthitic intergrowths of albite with the potash feldspars; next, to the amount of soda-lime feldspar present in the rocks; and, lastly, to the potash being replaced, in part, by soda in the straight potash feldspar molecule (analyses IVa and XIa).

GENETIC RELATIONSHIP OF PHENOCRYST TO GROUNDMASS

Evidences of intratelluric origin.—The evidences upon which the formation of phenocrysts at great depths and under conditions different from those of the groundmass constituents in igneous, intrusive rocks, rest have been adequately discussed by Pirsson[1] and are shown to be: (1) Contrast in size and crystal form of phenocryst to the groundmass constituents. (2) The fluidal arrangement, common in many cases, to the porphyritic minerals. (3) Irregularity of form, traceable to corrosion or resorption of the crystal (phenocryst) by the magma.[2]

These will be discussed in relation to the phenocrysts of the Georgia porphyritic granites under the next heading.

Evidences of contemporaneous origin.—The evidences favoring contemporaneous origin of the phenocrysts in the Georgia porphyritic granites may, for convenience, be discussed under (1) megascopic proofs: geologic or field observations; and (2) microscopic proofs: study of the thin sections of the rocks.

Both the macro- and microscopic characteristics of the Georgia porphyritic granites have been described in considerable detail under the individual areas above. Hence it is only necessary here to summarize and classify the facts pointing to a contemporaneous origin for the phenocrysts.

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[1] Amer. Journ. Sci., 1899, Vol. VII, p. 278.

[2] IDDINGS, J. P.: Bulletin, Phil. Soc. of Washington, 1889, Vol. XI, p. 77.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	IVa	XIa
SiO_2	70.90 1.181	70.88 1.181	70.24 1.170	69.77 1.162	69.48 1.158	69.37 1.157	69.17 1.152	69.13 1.152	67.62 1.127	66.31 1.105	63.65 1.060	64.64	64.40
Al_2O_3	15.86 .155	15.86 .155	16.78 .164	17.05 .167	16.64 .163	16.99 .166	16.47 .163	17.14 .168	16.29 .159	18.27 .179	20.46 .200	19.64	18.97
Fe_2O_3*	1.37 .008	1.77 .011	1.46 .009	1.60 .010	1.84 .011	1.99 .012	1.23 .007	1.52 .009	2.31 .014	2.51 .015	2.20 .013	0.37	0.37
CaO	2.15 .038	1.79 .032	2.00 .035	2.21 .039	2.32 .041	2.03 .036	2.02 .036	1.85 .033	2.37 .042	2.91 .052	3.28 .058	0.67	0.59
MgO	0.02 .001	0.93 .023	0.76 .019	0.99 .024	0.29 .007	0.84 .021	0.61 .015	0.79 .019	0.78 .019	1.22 .030	1.50 .037	tr.	tr.
K_2O	4.62 .049	4.64 .049	5.03 .053	4.08 .043	4.49 .047	4.54 .048	4.41 .047	5.49 .058	4.58 .048	4.09 .043	4.58 .048	10.00	11.40
Na_2O	5.05 .081	3.94 .063	3.70 .059	3.97 .064	4.74 .076	3.44 .055	4.89 .078	4.06 .065	5.42 .090	3.69 .059	4.75 .076	3.06	3.60
Igni	0.50	0.49	0.50	0.44	0.46	0.55	1.06	0.52	0.32	0.62	0.42	0.22	0.19
Total.....	100.47	100.30	100.47	100.11	100.26	99.75	99.85	100.50	99.69	99.61	100.84	98.60	99.52

* All iron was determined as Fe_2O_3.

I. Georgia Quincy Granite Company's Quarry, near Sparta, Hancock county.
II. A. J. McElwaney's place, near Line Creek, Fayette county.
III. Flat (Cedar) Rock, 9 miles west of Zebulon, Pike county.
IV. Heggie-Rock, 3 miles east of Appling, Columbia county.
V. Sparta Quarry, Hancock county,
VI. Mrs. L. N. Calloway's place, 3 miles southeast from Milledgeville, Baldwin county.
VII. The Moseley Quarry, 6 miles south of Atlanta, Fulton county.
VIII. Porphyritic granite area, 10 miles south of Greensboro, Greene county.
IX. The Charley Rocker Quarry, near Sparta, Hancock county.
X. Brinkley place, near Camak, Warren county.
XI. The J. R. McCollum place, near Coweta Station, Coweta county.
IVa. Feldspar phenocrysts from Heggie-Rock, Coumbia county.
XIa. Feldspar phenocrysts from the J. R. McCollum place, Coweta county.

The field observations include (1) passage or gradation interiorly from the porphyritic facies, peripherally into an even-granular, coarse-textured granite of the same mineral and chemical composition. The peripheral or border zones of the porphyritic granite masses, representing the granular facies of the rock, generally attain considerable widths in the Georgia areas, from which phenocrysts are entirely absent. (2) The general absence of definite (fluidal) arrangement or orientation of the phenocrysts in the groundmass. The Greene county porphyritic granite mass possibly affords, in places, the faintest possible evidence of the tabular phenocrysts having moved in a liquid magma, with partial definite arrangement or orientation. If these special parts of the area be accepted as indicative of flow structure, however, then we must also grant the contemporaneity in crystallization of the groundmass constituents for the same portions of the mass; for all of the other constituents, particularly biotite, are abundantly included in the phenocrysts of all parts of the area. The included biotite plates are equally as large as the same constituent in the groundmass. The other inclusions are microscopic in size and proportions.

The Brinkley-Place Holder's-Mill porphyritic granite has a pronounced foliated structure. This structure resembles in certain particulars, in places, the fluxion structure of some rocks, but in this case the foliation is shown to be secondary or derived — induced — and not primary or fluidal.

The phenocrysts are badly fractured and drawn out as "augen" between the inclosing groundmass minerals, roughly parallel in the direction of their longer diameters. Furthermore, the microscope indicates abundant squeezing and mashing and peripheral shattering of the quartz and feldspars, so characteristic of a secondary structure resulting from dynamometamorphism.

The microscopic evidence, favoring contemporaneous origin of the phenocrysts with the groundmass constituents, is chiefly that of prevailing abundance of all the groundmass minerals, as inclusions in the phenocrysts, for the areas studied. In every case the biotite inclusions are readily distinguished megascopically.

The comparative abundance of inclusions[1] in the phenocrysts, and the form and size of the latter, suggest a rapid growth for the porphyritic crystals. The inclusions are not limited to and distributed through the outer zones of the phenocrysts, indicative of different periods in crystal growth with reference to the groundmass constituents, but, on the contrary, they are scattered through all parts of the crystal (phenocryst). The inclusions are grouped, with few exceptions, without regard to crystallographic lines or directions, and without uniform orientation with reference to the host and each other. No external evidence in the nature of crowding and pushing aside of the adjacent groundmass microlites during the growth and expansion of the phenocrysts has been observed, resulting in some cases, as mentioned by Pirsson,[2] in the resemblance to the flow structure.

The microscope, as a rule, fails to indicate, in the rock sections studied, rounding or irregularity in crystal outline of the original phenocryst resulting from a partial resorption or corrosion of the crystals by the magma in the Georgia areas.

Phenocrysts of roughly idiomorphic outlines — flat, tubular- and irregular-allotriomorphic forms — appear, with the former predominating in most of the areas. In view of confirmatory evidence, elsewhere stated in this paper, idiomorphism among the phenocrysts in the Georgia rocks could in no-wise be accepted as resulting from formation at greater depths and under entirely different conditions from the other constituents. In the absence of all other evidence it would be difficult to prove that form alone was a definite criterion favoring intratelluric origin. Pirsson[3] has shown that contrast in crystal form and size may very well be explained in an entirely different way.

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[1] *Ibid.*, p. 80.

[2] Op. cit., pp. 276, 277.

[3] *Ibid.*, pp. 278–280; see also CROSBY, W. O.: Amer. Geol., 1900, Vol. XXV, pp. 299–310.

The absence of (*a*) definite arrangement or orientation among the phenocrysts; (*b*) of phenocrysts from the border zones of the massif — gradation from an interior porphyritic facies peripherally into an even-granular granite of coarse texture and the same mineral and chemical composition; (*c*) the further absence of evidence of magmatic resorption or corrosion of the phenocrysts; and (*d*) the presence of abundant inclusions of all the groundmass constituents, characterizing the generally tabular phenocrysts of the Georgia porphyritic granites, fully justify the conclusion that the phenocrysts in these rocks were formed *in place*, and are not intratelluric in origin.

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